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OPTICAL INHOMOGENEITIES IN PUMPED LASERS (U)

VOLUME II

FINAL REPORT
MAY 1967

Contract No. Nonr 4875 (00)
ARPA Order No. 306
Project No. 4730

Office of Naval Research
Washington, D.C.

Prepared by

Dr. Charles J. Koester, Project Manager
Research Division
American Optical Company
Southbridge, Massachusetts

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OPTICAL INHOMOGENEITIES IN PUMPED LASERS

1. (S) Calculation of Thermal Distortion for a Given Laser Output

The numbers used in the unclassified portion of this final report were either arbitrarily chosen, or else based on published data, e.g., the flashlamp data in Fig. 6.

We now desire to apply the results to lasers with specific performance, e.g. 10^3 to 10^4 j/cm². The approach taken is semi-empirical. We start from the fact that with an unclad glass laser rod close-wrapped to a flashlamp of about the same diameter, overall efficiency of about 4% can be obtained. That is,

$$E_o = .04\ E_{in} = .04\ \frac{CV^2}{2} \tag{s 1}$$

where E_o = laser energy output

E_{in} = electrical energy into flashlamp.

The flashlamp and pumping configuration are about 60% efficient in converting electrical energy to radiant energy incident on the laser rod.

$$E_{rad} = 0.6\ E_{in} \tag{s 2}$$

With these two empirical results, we can proceed to calculate the laser length necessary to achieve a given output,

$$E_o = E_D \cdot A = E_D \cdot \frac{\pi}{4} d^2 \tag{s 3}$$

where E_D = laser output energy density,

A = cross-sectional area,

d = diameter of active (core) area.

Now

$$E_{rad} = E_M(R)\ \pi DL \tag{s 4}$$

where $E_M(R)$ = energy density of pumping radiation at surface of rod (Eq. 39)

D = diameter of rod (outer surface in case of clad rod)

L = length of rod.

Substitution of (S 2), (S 3), and (S 4) into (S 1) yields

$$E_D A = .04 \frac{E_M(R)\ \pi DL}{0.6}$$

Solving for L:

$$L = \frac{15 E_D\ d^2}{4 E_M(R)\ D} \qquad \text{(S 5)}$$

For the plane strain case, the average path difference (Eq.9) is used

$$\overline{\Delta P} = nLT \left\{ \alpha_n + \frac{\alpha}{1-s} \left[\frac{3-5s}{2} \frac{p}{v} + \frac{1-3s}{2} \frac{q}{v} \right] \right\} \qquad \text{(S 6)}$$

For the plane stress case (immersed discs), the average path difference (Eq. 14) is used

$$\overline{\Delta P}' = nLT \left\{ \alpha_n + \alpha \left[\frac{n-n'}{n} (1+s) + \frac{1-3s}{2} \frac{p}{v} + \frac{1-s}{2} \frac{q}{v} \right] \right\} \qquad \text{(S 7)}$$

In Table S-I, Eqs. (S 6) and (S 7) have been used to calculate the maximum optical path difference, $\overline{\Delta P}$, between any two rays traveling parallel to the axis.

Several comments are in order on the figures in the table. Some of the lengths, L, are greater than presently available in a single rod. Therefore, to attain the desired energy output, several rods in series would be required, and the relative importance of end effects would be increased. For all the rod cases, the plane strain contribution to the optical path distortion, ΔP, is dominant. That is, the maximum end effect differential of about 0.4 micron per end (see Fig. S1) for the unclad rod is small compared to the plane strain.

The beamspread which would result from the values of $\overline{\Delta P}$ for the rod are greater than the diffraction limit, by a factor of roughly $\frac{2\overline{\Delta P}}{D/2} \Big/ \frac{1.22\ \lambda}{D} = 3.3 \frac{\Delta P}{\lambda}$.

To achieve a diffraction limited beam, the classical criterion is to keep the wavefront within $\lambda/4$ of a plane wave, i.e., $|\overline{\Delta P}| \le \lambda/4 = 0.26\ \mu m$, for $\lambda = 1.06\ \mu m$.

TABLE S-I
Optical Path Differences Accompanying an Output of 1000 j/cm^2

GLASS ROD

Type of Rod	Glass	d cm	D cm	$E_M(R)$ j/cm^2	ΔT °C	L for 1000 j/cm^2	$\overline{\Delta P}$ Plane Strain
Solid	3835	.9	.9	9.6 (1)	1.8°	350 cm	11.2 μm
Solid	3835	.9	.9	48.1 (2)	14°	70	17.5
Solid	3835	.9	.9	153 (3)	44°	22	17.5
Solid	1204 (5)	.9	.9	48.1	14°	70	7.1
Water clad	1204 (5)	.9	3.76	9.6	2.0	274 (4)	4.0
Glass clad	1204 (5)	.9	1.35	9.6	1.2	306	2.7

IMMERSED DISC, n′ = 1.33

Type	Glass	d	D	$E_M(R)$	ΔT	L total glass thickness	$\overline{\Delta P}$ Plane Stress
Disc	3835	.9	3.76	9.6	2.0	274	-2.6 μm
Disc	1263 (5)	.0	3.76	9.6	2.0	274 cm	-1.3

---

1. 9.6 j/cm^2 corresponds to 1700 amp/cm^2 in the flashlamp
2. 48.1 j/cm^2 corresponds to 5300 amp/cm^2 in the flashlamp
3. 153 j/cm^2, a postulated pumping energy density used to calculate Fig. S1
4. Length L_{WC} of the water clad rod was calculated by using Eq. (S 5) to find L, then use the relation $L_{WC} = \frac{L}{.34}$.

   The reason for the factor 1/.34 is that the thick water cladding makes the pumping less efficient. The factor .34 was found from the weighted areas under curves (1) and (3) in Fig. 11 by calculating

$$\frac{D_{unclad}}{D_{water\ clad}} \quad \frac{\int_0^R \Delta T_{(1)} x \, dx}{\int_0^R \Delta T_3 \, x \, dx} = \frac{1}{4.17} \, \frac{30.87}{21.74} = .34.$$

5. For all glasses, the measured values of α and α_n are used. However, for ease of comparison, the same absorption curve was used for glasses 1204 and 1263 as for 3835. This implicitly assumes that the neodymium concentrations in glasses 1204 and 1263 (1.03 and 2.03% respectively) could be increased to that of 3835 (5%) without significantly changing the values of α and α_n.

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2. (U) Steps to Achieve Further Athermalization

To reach this goal of complete athermalization, two possible directions are indicated. In both cases it is assumed that the optical rotator is used between laser elements to average the path for the two polarizations.

A. For long rods

(1) Utilize a glass cladding of appropriate thickness (and index) to minimize the temperature differential within the rod. The cladding thickness can be determined for a particular RF value of the core either experimentally or theoretically.

(2) Athermalize the glass for the plane strain case. (This work is in progress).

(3) For the final correction, calculate the end effects for the expected temperature distribution and the glass type.

a. adjust the values of α_n and α for the glass as described in Section 6 so as to minimize the end effect.

or b. design a correction lens to bring the wavefront within tolerance for the maximum time during the laser pulse.

or c. combine steps (3)a and b.

B. For immersed discs

In this case there are more unknown factors, such as the change in optical path through the immersion liquid during pumping.

(1) Select liquids which meet the requirements of very low absorption for laser and pumping wavelengths.

(2) Filter from the pump light wavelengths which are absorbed by the liquid.

(3) For each such liquid evaluate $\frac{1}{nL}\frac{d\overline{P}'}{dT}$ by Eq. (14) for each candidate glass.

(4) Having found a good glass-liquid combination, calculate the actual $\Delta\overline{P}'$ for the disc geometry (i.e., determine departures from the plane stress case, as in Section 6).

(5) For the final correction, adjust the index n′ of the liquid by solution or by temperature control. If necessary, steps (3)a,b,c, from the rod case could also be utilized.

3. (S) Conclusions

The conclusions to be drawn from this effort are, therefore, that for 10^3 j/cm² the thermal distortion problem is severe for present glasses and configurations. The analysis, however, suggests two procedures which would lead to improved athermalization. Two of the steps in these procedures, glass cladding of rods and athermalization of the laser core have been shown to yield substantial gains.

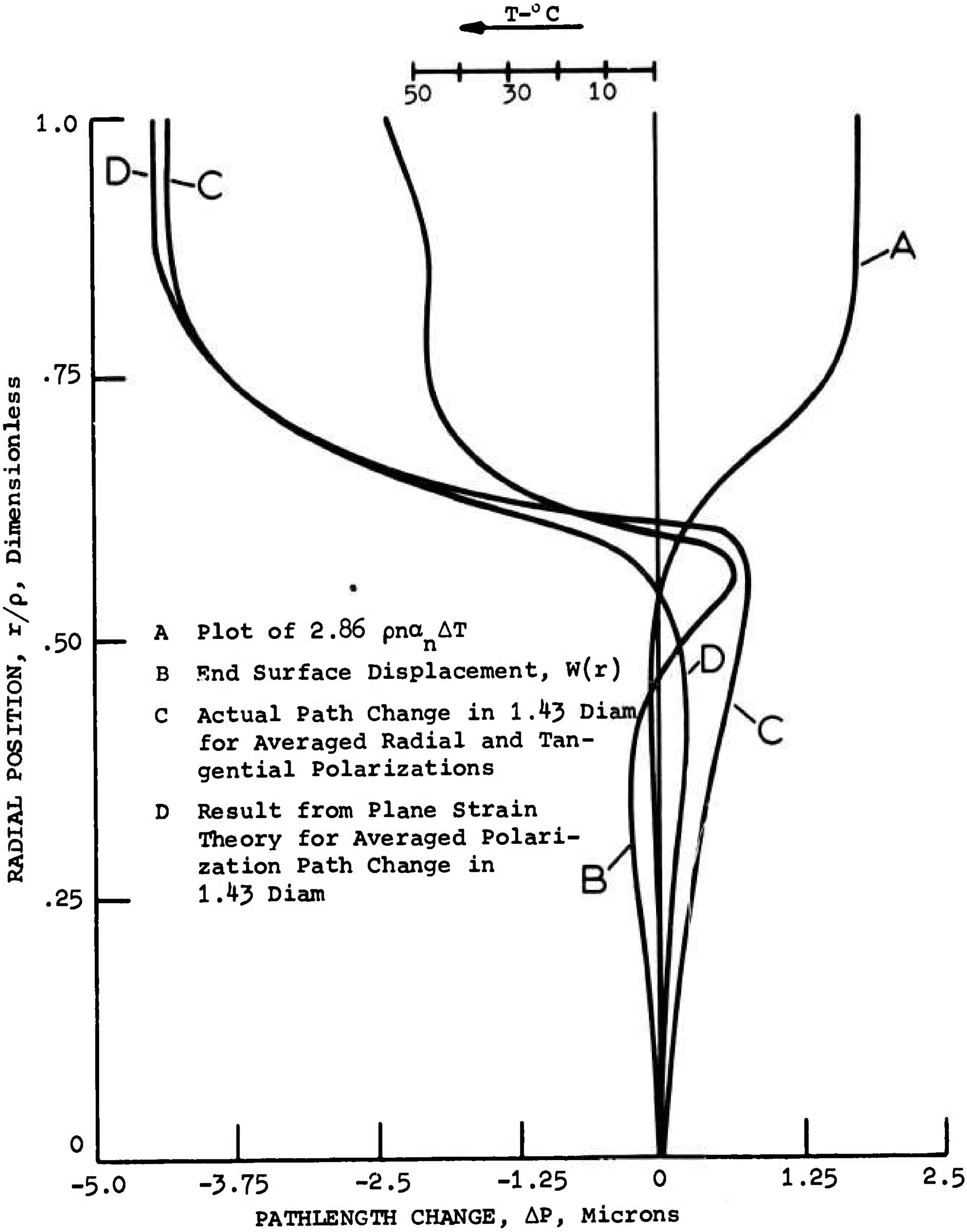

Figure S1. Relative temperature change, end face distortion, and optical path variation for the end region of an 0.9 cm diam. 3835 glass laser rod pumped at 153 j/cm².

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